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ABSTRACT

Based on the fact that the individual human mind is limited, conceptual frameworks and innovative systems in support of social interaction are a necessity rather than a luxury for the future information society. Conceptual frameworks need to be grounded in distributed cognition. Because "a group has no head," collaboratively constructed and evolved information repositories are of critical importance to support shared understanding, negotiation, critiquing, and organizational learning. Derived from this conceptual framework, requirements for computational environments supporting social interactions are identified. Specific environments (for example, domain-oriented design environments and organizational memories) illustrate the challenges of creating open, evolvable systems and of contextualizing information. These implications for social interaction are derived from the conceptual framework and the systems and include the need to allow users to be designers and active contributors, the importance of understanding the social and motivational issues, and the new conceptualizations of the World Wide Web. (Appendixes include a selected glossary and list of 27 references.) (YLB)

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Crossroads of the New Millennium

Distributed Cognition And Systems For Supporting Social Interaction

Prepared and Presented

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Abstract

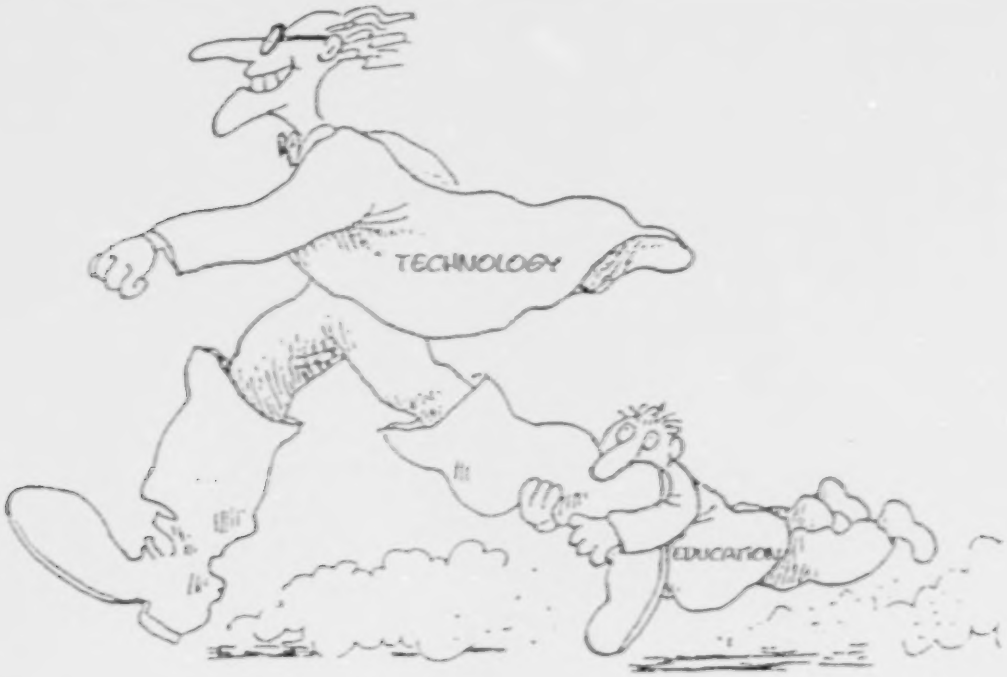
Based on the fact that the individual human mind is limited, conceptual frameworks and innovative systems in support of social interaction are a necessity rather than a luxury for our future information society. Conceptual frameworks need to be grounded in distributed cognition. Because "a group has no head," collaboratively constructed and evolved information repositories are of critical importance to support shared understanding, negotiation, critiquing, and organisational learning. Derived from this conceptual framework, requirements for computational environments supporting social interactions are described. Specific environments (e.g., domain-oriented design environments, organisational memories) illustrate the challenges of creating open, evolvable systems and of contextualising information. The implications for social interaction (such as the need to allow users to be designers and active contributors, the importance of understanding the social and motivational issues, and the new conceptualisations of the World Wide Web) are derived from the conceptual framework and the systems.

Distributed Cognition and Systems for Supporting Social Interaction

Learning needs to be examined throughout one's lifespan because the traditional notion of a divided lifetime — education followed by work — is no longer tenable [Gardner, 1991]. Professional activity has become so knowledge-intensive and fluid in content that learning has become an integral and irremovable part of work activities. Learning is a new form of labour, and working often is (and needs to be) a collaborative effort among colleagues and peers. In the emerging information society, an educated person will be someone who is willing and able to consider learning as a lifelong process. More and more knowledge, especially advanced knowledge, is acquired well past the age of formal schooling, and in many situations through educational processes that do not centre on traditional schools [Illich, 1971].

Lifelong learning has emerged as one of the major challenges for the worldwide knowledge society of the future. A variety of recent events supports this claim: (1) 1996 was the "European Year of Lifelong Learning," (2) UNESCO has included "Lifetime Education" as one of the key issues in its planning, and (3) the G7/G8 countries have named "Lifelong Learning" as a main strategy in the fight against unemployment. Despite this great interest, there are very few encompassing efforts to tackle the problem in a coherent way. Lifelong learning is comprehensive; it cannot be investigated in isolation by looking just at individual parts of it, such as K-12 education, university education, or at worker re-education.

Lifelong learning is more than adult education that is often only restricted to providing people with minimal opportunities in school-like learning settings during their adult life. The challenge for lifelong learning is to fundamentally rethink learning, teaching, and education for the information age in an attempt to change mindsets [Fischer, 1999a]. It involves and engages learners of all ages in acquiring and applying knowledge and skills in the context of authentic, self-directed problems, and it exploits the possibilities offered by new media. In the future, learning and working should take place, in most cases, as a *collaborative effort* among teachers, learners, peers, and colleagues.



BEYOND INDIVIDUAL HUMAN MINDS

The Limitation of the Unaided, Individual Human Mind. The power of the unaided, individual mind is highly overrated because without the use of external aids, memory, thought, and reasoning are all constrained [Norman, 1993]. As illustrated in Figure 1, the basic capabilities of the unaided, individual human mind has changed little over time. For the design of cognitive artifacts, it is important to know these basic capabilities; some of them, such as working memory, long-term memory, perceptual processors, cognitive processors, and motor processor and their basic characteristics are described [Card et al., 1983].

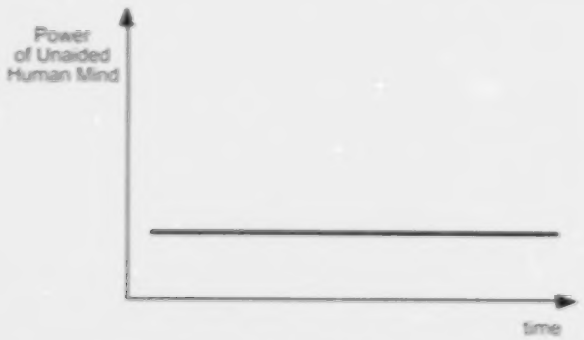


Figure 1: The power of the unaided individual human

The Tension between Human and Computational Power. In sharp contrast to the negligible change of the basic capabilities of the unaided, individual human mind, computational and communication technologies have changed dramatically. Moore's law (illustrated qualitatively in Figure 3) is the principle that computer capacity doubles every eighteen months. The principle, operative since the dawn of the computer age, shows no sign of abating and its implications have provided unique possibilities for creating new cognitive artifacts. One of the basic misunderstandings has been that while these technologies are necessary, they do not sufficiently allow humans to work more creatively and efficiently, to learn and understand more, and to collaborate more [Landauer, 1995].

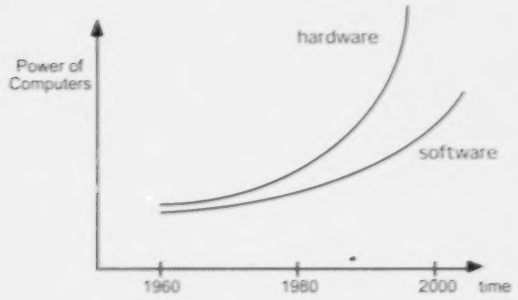


Figure 3: Computing power increases at an exponential rate

The Collective Human Mind — Exploiting Social Interaction. The Renaissance scholar does not exist anymore. Human beings have a bounded rationality — making satisfying instead of optimising a necessity [Simon, 1996]. There is only so much we can remember and there is only so much we can learn. Talented people require approximately a decade to reach top professional proficiency. When a domain reaches a point where the knowledge for skillful professional practice cannot be acquired in a decade, specialisation will increase, collaboration will become a necessity, and practitioners will make increasing use of reference aids, such as printed and computational media supporting external cognition [Bruner, 1996].

Much of our intelligence and creativity results from the collective memory of *communities of practice* and of the artifacts and technology surrounding them [Fischer, 1999b]. Though creative individuals are often thought of as working in isolation, the role of interacting and

collaborating with other individuals is critical. Creative activity grows out of the relationship between an individual and the world of his or her work, and out of the ties between an individual and other human beings. The basic human capacities are differentially organised and elaborated into complex systems of higher psychological functions, depending on the actual activities in which people engage. These activities depend crucially on the historical and cultural circumstances in which people live [Resnick et al., 1991].

Figure 4 illustrates the major fundamental human inventions and creations that have increased the power of the unaided, individual human mind. Two important questions to ask today are: (1) Will computational and communication media equally impact humans as reading, writing and the printing press did in the past? (2) Will we be able to achieve another qualitative increase (indicated by the dashed line in Figure 4) by the development of new media and new technologies which exploit the possibilities of the *collective* human mind through social interactions?

Figure 4: The Power of the Collective, Aided Human Mind

A Motivating Example for Social Interaction. One of our collaborating companies employs 700 help desk people. These employees help customers all day and every day to solve their problems. Thus, this setting appears to be an ideal environment to take advantage of social interactions, where the group at large could benefit from the creative act of the individual employee. In our example, help desk person **N** expends considerable effort to solve a customer's difficult problem. How should this effort be documented and shared with the other help desk people? Should person **N** *broadcast* (using some kind of "push-technology") this problem and its solution to the 699 other help desk people, as illustrated in Figure 5?

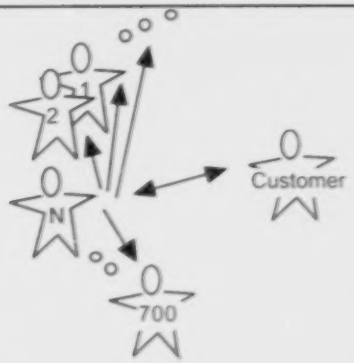


Figure 5: Information Overflow of Decontextualised Information Caused by Broadcasting

We claim that the answer is "no", because in general this information will not be relevant to the other help desk people at the same point in time. All of these people (like most knowledge workers) do not suffer from a scarcity of information, but from an information overload problem; and this problem is worsened by receiving more decontextualised information whose relevance is not recognised by the receiver at the same moment in time.

The more promising strategy is illustrated in Figure 6. The problem solving knowledge created and documented by person **N** is captured in an *information repository* (such as an organisational memory). It is made available either upon request (using "pull" technologies) or volunteered by the system (employing "push" technologies). So, in the future, when any of the 700 help desk employees encounters a problem in which the solution of person **N** is relevant, the information is readily available.

This example represents the kinds of experiences that are important for social interaction. One of the core challenges for social interaction is to collect creative solutions by individuals

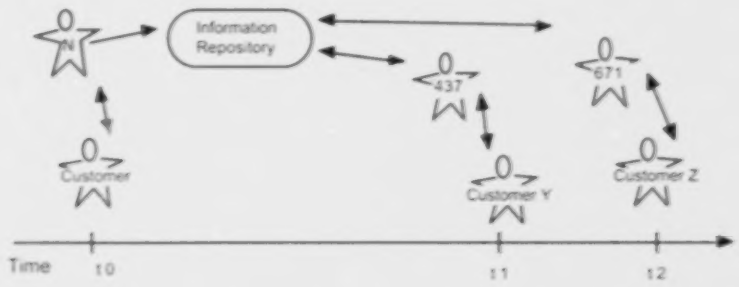


Figure 6: Contextualising Information to the Task at Hand and Supporting Learning on Demand

and make them available to others who encounter similar problems. This core challenge raises difficult technical issues such as: (1) computationally tractable representations of experiences, (2) retrieval technologies that recognise complex as well as surface similarities, (3) capturing significant portions of knowledge that practitioners generate in their work, (4) the effort required to contribute to organisational memory must be minimal so it will not interfere with getting the higher prioritised work done, and (5) developing a culture in which individuals are motivated to work for the good of the group or organisation [Grudin, 1994].

A CONCEPTUAL FRAMEWORK FOR SOCIAL INTERACTION

The basic foundation for social interaction is that people think, work, and learn in conjunction or partnership with others, with the help of culturally provided tools and artifacts. For a conceptual framework (or theory) of social interaction to be interesting, to inspire, to guide and to inform the development of new media supporting social interaction, it should contain some specifications on how social interactions can be improved or altered in some significant way. A focus on social interaction has shifted our *internalist* view of seeing the mind as an information processor, and by assuming that the mind's operation is characterisable independent of its relationship to the external world to a *distributed* cognition view.

A Group has No Head. Distributed cognition [Norman, 1993] emphasises that the heart of intelligent human performance is not the individual human mind but groups of minds in interaction with each other and minds interacting with tools and artifacts. It is important to understand the fundamental difference of distributed cognition as it operates for the aided individual human mind. Distributed cognition between the individual human mind and artifacts (such as memory systems) often function well, because the required knowledge that an individual needs is distributed between the mind and the world (for example: an address book, a folder system of e-mail messages, or a file system). But a group has no head — therefore externalisations are critically more important for social interaction. Externalisations can create a record of our mental efforts, one that is "outside us" rather than vaguely in memory, and can represent situations that can critique, negotiate, and talk back to us.

Symmetry of Ignorance. As argued above, when a domain reaches a point where the knowledge for skillful professional practice cannot be acquired in a decade, specialisation will increase, collaboration will become a necessity, and practitioners will make increasing use of reference aids, such as printed and computational media supporting external cognition. Design [Simon, 1996] is one such domain par excellence. Complexity in design arises from the need to synthesise different perspectives of a problem, the management of large amounts of information relevant to a design task, and understanding the design decisions that have determined the long-term evolution of a designed artifact. The social interaction among stakeholders in design can be characterised by a "symmetry of ignorance" [Rittel, 1984], or an "asymmetry of knowledge". In designing artifacts, designers rely on the expertise of others [Galegher et al., 1990; Resnick et al., 1991] by referring to textbooks, standards, legal constraints, and especially previous design efforts. Project complexity forces large and heterogeneous groups to work together on projects over long periods of time. Knowledge bases should include not only knowledge about the design process but also knowledge about artifacts of that process — parts used in designing artifacts, subassemblies previously created by other design efforts, and the rationale for previous design decisions. Designers generally have a limited awareness and understanding of how the work of other designers within the project (or in similar projects) is relevant to their own part of the design task. The large and growing discrepancy between the amount of such relevant knowledge and the amount any one designer can possibly remember imposes a limit on a design in progress. Overcoming this limit is a central challenge for developers of systems that support social interaction [Nakakoji, 1998].

Organisational Learning and Organisational Memories. *Organisational Learning* focuses on recording knowledge gained through experience (in the short term), and actively making that knowledge available to others when it is relevant to their particular task (in the long term) [Fischer et al., 1996]. A central component of organisational learning is a repository for storing knowledge in an organisational memory. However, the mere presence of an organisational memory system does not ensure that an organisation will learn. Today, information is not a scarce commodity — the problem is not just to accumulate information, but to deliver the *right* knowledge at the *right* time to the *right* person in the *right* way. Organisational learning happens only when the contents of organisational memory are utilised

effectively in the service of doing work. Efficient support for organisational learning raises many unresolved issues of how can we create a working and learning culture in which individuals are encouraged and willing to share; and how do we effectively collect individual knowledge and make it easily accessible to the entire organisation?

For sustained organisational learning, three seemingly disparate goals must be served simultaneously. Organisational memory must (1) be extended and updated as it is used to support work practices; (2) be continually reorganised to integrate new information and new concerns; and (3) serve work by making stored information relevant to the new task-at-hand. Organisational learning is a continuous cycle in which organisational memories play a pivotal role:

- Individual projects serve organisational memory by adding new knowledge that is produced in the course of doing work, such as artifacts, practices, rationale, and communications.
- Organisational memories are sustained in a useful condition through a combination of computational processes providing information and people actively contributing.
- Organisational memory serves work by providing relevant knowledge when it is needed, such as solutions to similar problems, design principles, or advice.

The intimate relationship between organisational memory and work practices implies that the contents of organisational memories must be easily accessible *within the context of work*. Computational support for organisational learning, therefore, must tightly integrate tools for doing work with tools for accessing the contents of organisational memories. Processes of information capturing, structuring, and delivery must be computationally supported as much as possible or they simply will not get done.

Organisational memories are information systems that are used to record knowledge for the purpose of making this knowledge useful to individuals and projects throughout the community of practice and into the future. Ideally, an organisational memory allows individuals within the community to benefit from the experiences and insights of others, by *actively* informing work practices at the point when the information is actually needed. That is, an organisational memory should not be simply a passive repository of information, but an

interactive medium within which collaborative work can actually be conducted and through which the communication about work can take place and be established. Systems that support *organisational learning* and *organisational memories* will be useful for professionals working on complex tasks in large team environments. An example of an organisational memory is GIMMe, the Group Interactive Memory Manager [Fischer et al., 1996] which captures group email, automatically categorises it, and then provides context-sensitive search capabilities. These systems will have to be enhanced to capture richer types of information and provide more powerful categorisation and search techniques.

EXAMPLES OF SYSTEMS IN SUPPORT OF SOCIAL INTERACTION

Domain-Oriented Design Environments. In our own past research efforts we have developed conceptual frameworks to empower individuals by developing domain-oriented design environments [Fischer, 1994] in a variety of different domains. By being domain-oriented, these environments support *human problem-domain communication*, making the computer invisible and bringing tasks to the forefront. Domain-oriented design environments (created over time as a joint effort among clients, domain designers, and environment developers) can empower individuals by:

1. letting them articulate a partial description of their tasks with the help of a specification component (see pane 4),
2. supporting the creation of an artifact with a construction component (see pane 2 and 3),
3. using a catalog of previous designs supporting design by modification (see pane 5),
4. signaling potential breakdowns with a critiquing component,
5. supporting the exploration of argumentation and design rationale (see pane 1), and
6. providing additional feedback with a simulation component (see pane 3).

The Envisionment and Discovery Collaboratory. The Envisionment and Discovery Collaboratory (EDC) (http://www.cs.colorado.edu/~l3d/systems/EDC/) [Arias et al., 2000] is a domain-oriented design environment under development supporting social interaction by creating shared understanding among various stakeholders, contextualising information to the task-at-hand, and creating objects-to-think-with in collaborative design activities. The EDC framework is applicable to different domains, but our initial effort has focused on the domains of urban planning and decision making, specifically in transportation planning and community development. Creating shared understanding requires a culture in which stakeholders see themselves as reflective practitioners rather than all-knowing experts [Schön, 1983]. The "symmetry of ignorance" is a defining characteristic of such collaborative design activities: stakeholders are aware that while they each possess relevant knowledge, none of them has all the relevant knowledge.

Figure 7: The Envisionment and Discovery Collaboratory (EDC)

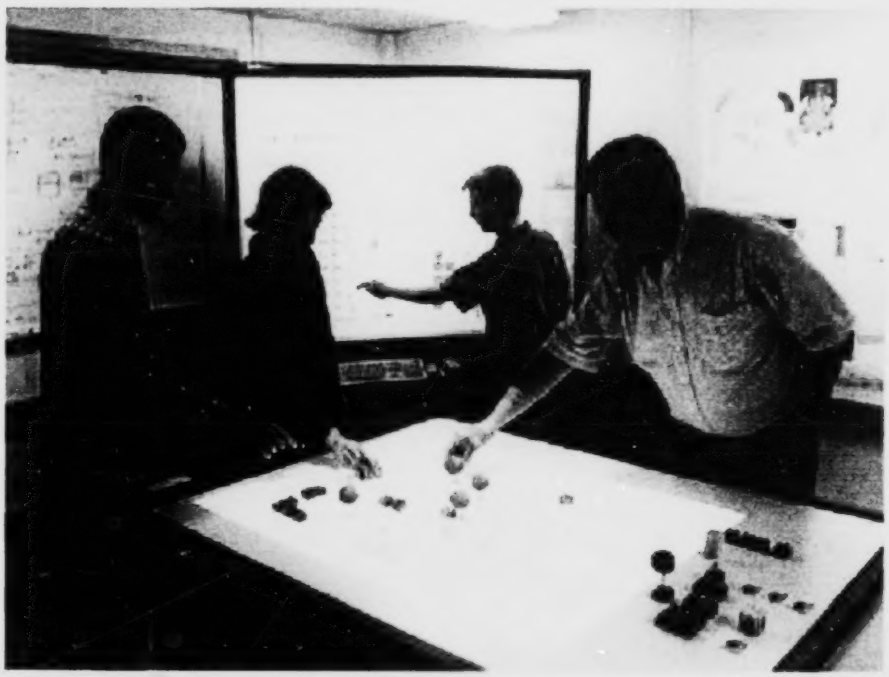


Figure 7 shows the current realisation of the EDC environment. Individuals using the EDC convene around a computationally enhanced table, shown in the forefront of the figure. This table serves as the Action Space for the EDC. Currently realised as a touch sensitive surface, the Action Space allows users to manipulate the computational simulation projected on the

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surface by interacting with the physical objects placed on the table. A second computer driving another touch-sensitive (vertical) surface is shown behind the Action Space table. This computational whiteboard serves as the EDC's Reflection Space. In the figure, users are filling out a Web-based transportation survey that is associated with the model being constructed. The Reflection and Action Spaces are connected by communication between the two computers using the Web as a medium. The entire physical space, through the immersion of people *within* the representations of the problem-solving task, creates an integrated human/computer system grounded in the physical world [Arias et al., 1997].

Much development of technology for learning and design builds on or is constrained by the "single user/single computer" interaction model. The EDC emphasises the creation of shared interaction and the cultural embedding for learning and design within the context of communities of learners. The EDC supports relevant crucial processes for social interaction by:

- dealing with a set of possible worlds effectively; thus, exploring design alternatives where an environment for a design dialog can be created.
- using the symmetry of ignorance (i.e., that all involved stakeholders can actively contribute) as a source of power for mutual learning by providing all stakeholders with means to express their ideas and their concerns.
- incorporating an emerging design in a set of external memory structures, and recording the design process and the design rationale.
- creating modifiable models, which help us create a shared understanding by having a "conversation" with the artifacts created, and thus, replacing the anticipation of the consequences of our assumptions by analysis.
- using domain-orientation to bring tasks to the forefront and support human problem-domain communication.
- increasing the "back-talk" of the artifacts with critics [Fischer et al., 1998].
- using simulations to engage in "what-if" games [Repenning, 1999].

The EDC is a contribution to creating a new generation of collaborative domain-oriented design environments. It shifts the emphasis away from the computer screen as the focal point to creating an *immersive* environment in which stakeholders can incrementally create a shared

understanding through collaborative design. It is an environment that is not restricted to the delivery of predigested information to individuals, but it provides opportunities and resources for design activities embedded in social debates and discussions in which *all* stakeholders can actively contribute rather than being confined to passive consumer roles.

IMPLICATIONS

From Consumers to Designers. Social interaction is impossible in communities where most members regard themselves as consumers. Consumers must evolve into power-users and co-developers who use artifacts and at the same time be able to modify and extend them. A strict separation between these two groups is undesirable and unproductive. One of the biggest potentials of information technology (which provides the potential to lead to another qualitative level of support for the collective, aided human mind; see Figure 4) is allowing people the option to become designers by changing and enhancing a software system. After all, software as already indicated by its name, should be "soft." One of the major contributions that information technology can lend to the world is to understand and exploit the potential of the malleable nature of software.

Individuals acting as designers must acquire a *new mindset* — no longer passive receivers of knowledge, but instead as active researchers, constructors, and communicators of knowledge. Knowledge is no longer handed down from above, but instead is constructed collaboratively in the context of work. Empowering individuals with convivial tools is grounded in the fundamental belief that humans (albeit not all, not all the time, nor in all contexts) want to be and act as designers [Fischer, 1998].

New Conceptualisations of the World Wide Web (WWW). Many people will argue that the most important new technology in support of social interaction is the WWW. The scope of this article does not allow to review all the new interesting developments, such as social filtering, recommender systems [Terveen et al., 1997], chat rooms, etc., but in analogy to the argument made with the exponential growth of computational power (see Figure 3), the WWW is a necessary medium for new forms of social interaction, but not a sufficient one. For example, the WWW in its current form does not support evolutionary design.

Figure 8 describes three different models of the WWW. Most WWW-based use engages the WWW as a broadcast medium (Model M1) in which content is predetermined at design time and placed on static WWW pages. Most popular general-purpose WWW tools provide support for the easy generation of this static content. As a broadcast medium, the WWW serves as a distribution channel and provides few opportunities for designers to interact with the information because the content was not originally designed to be interactive. Responding to the need for feedback from consumers, many WWW sites are evolving into forms that augment content with some communication channels. *Broadcast with feedback* (Model M2) provides links from consumer to producer such as allowing learners to provide feedback and ask questions by filling out forms. Although users can react to information provided by the author, this presentation model provides little support for evolution.

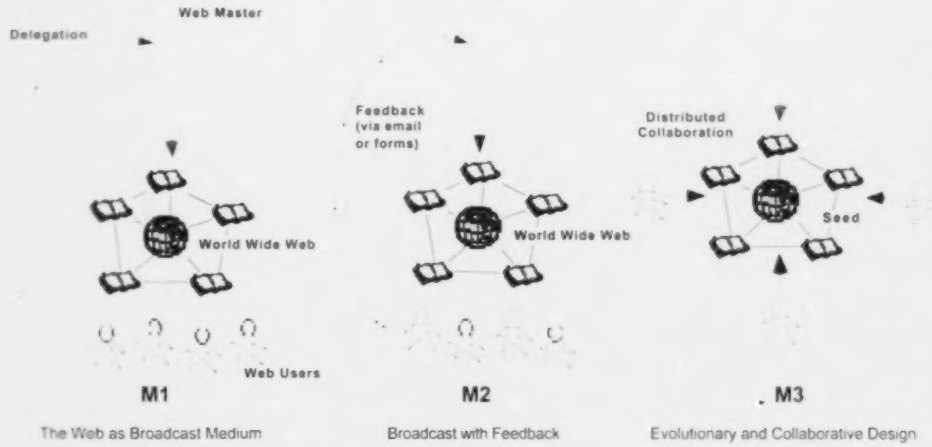

Figure 8: Making the World Wide Web a Medium for Collaborative, Evolutionary Design

To support social interaction, users need to be able to use the WWW to collaborate on projects by *actively* contributing and by learning from all contributors (Model M3). The evolution of content and ideas is now the responsibility of the participating community of practice, focusing on the distributed generation of content and the reflection upon it. When a wide variety of individuals collaborate in a co-operative forum, the unique skills of all the members become a valuable resource in making the WWW useful in its current context. This model of the WWW poses a number of technical challenges, including the ability to add to an information space without going through an intermediary, and to be able to modify the structure of the information space.

Decentralised Constructed Information Repositories. The M3 model is a useful framework for understanding the processes inherent in the development of *open systems* [Fischer & Scharff, 1998]. For example, the development of open-source software systems such as the Linux operation system [Raymond, 1999] provides an interesting example of a reliable, useful, and usable complex system built in a decentralised "Bazaar style" by many, rather than in a centralised "Cathedral style" by a few. The Linux development model treats users simultaneously as co-developers and designers [Fischer, 1998a].

Open systems are examples of the first steps in illustrating the power of social interaction based on community participation. In addition to Linux there are other interesting examples:

- **Gamelan** (http://www.gamelan.com) is one of the first community repositories of Java-related information. The primary users of Gamelan are Java developers looking for information about what other people are doing with Java. Gamelan is a forum to facilitate the self-directed learning of members of the emerging Java community. The software developers who use the content are also the primary contributors, continuously adding new resources to the Gamelan repository. Gamelan was originally designed to be the official clearinghouse for all third-party uses of Java, and the site attempts to support any work that uses Java.
- The **Educational Object Economy** (http://www.eoe.org/) provides a more focused system than Gamelan. Currently realised as a collection of Java objects (mostly completed applets) designed specifically for education, the target users of the Educational Object Economy are teachers (presumably acting as consumers of completed applets) wishing to use new interactive technology, and instructional designers interested in producing educational software. The Educational Object Economy's primary goal is to provide educators with a collection of useful resources ready to be used to help students learn.
- The **Netscape Communicator** (http://www.mozilla.org) allows the decentralised development of source code and supports the centralised integration.
- The **Agentsheets Behaviour Exchange** (http://www.agentsheets.com/) is an initial prototype of a domain-specific system for sharing computational artifacts.
- The **"open source" movement** [O'Reilly, 1999] that is currently emerging as a new paradigm for software development represents an exciting perspective for a society of

lifelong learners. The "open source" approach regards software and other cognitive artifacts not as a commodity to be consumed, but one that is collaboratively designed and constructed — providing a model for the knowledge society of the future (for more information on "open source" see: http://www.tuxedo.org/~esr/writings/).

One important common feature of these systems is their support for evolution [Fischer, 1998b]. As new knowledge becomes available, members of the community could share new developments with each other. In all four systems, the repository administrators set up an initial *seed* that structures how information is added, presented, and searched by users. The goal is to create useful information repositories in a decentralised fashion. Because all systems are envisioned as tools that evolve at the hands of a community of users, all four are prime candidates to study the challenges, strengths, and weaknesses of open systems and social interaction.

New Forms of Learning from a Lifelong Learning Perspective. Lifelong learning refers to a society in which learning possibilities exist for those who want to learn. Figure 9 summarises four innovative forms of lifelong learning, and addresses their contributions toward the creation of mindsets and the media requirements generated by them.

Form	Complementing Form	Contribution toward Mindset Creation	Major Challenges	Media Requirements
self-directed learning	prescribed learning	authentic problems	problem framing	understanding evolving tasks
learning on demand	learning in advance	coverage is impossible; obsolescence is guaranteed	identifying the breakdown leading to the demand; integration of working and learning	critics; supporting reflection-in-action
informal learning	formal learning	learning by being in the world	larger, purposive activities provide learning opportunities	end-user modifiability
organisational learning	individual learning	the individual human mind is limited	shared understanding	externalisations understandable by all stakeholders

Figure 9: Overview of New Forms of Learning Contributing to Lifelong Learning

CONCLUSIONS

Until recently, computational environments focused on the needs of individual users. As more people use computers for more complex tasks, it has become apparent that environments supporting social interactions among communities of practice, groups, and organisations are needed. However, this perspective does not necessitate the development of environments in which the interests of the group inevitably supersede those of the individual. Individuality makes a difference, and organisations get their strength to a large extent from the creativity and engagement of the individual. One of the important challenges for the future is to gain a better understanding of the relationship between the individual and the social.

ACKNOWLEDGMENTS.

The author would like to thank the members of the Centre for LifeLong Learning & Design (L3D) at the University of Colorado, who have made major contributions to the conceptual framework and systems described in this paper. Our research is supported by PFU, Tokyo, and Software Research Associates, Tokyo and Boulder. More information about the L3D Centre can be found at: http://www.cs.colorado.edu/~l3d/.

APPENDIX: BRIEF DESCRIPTION OF THE CONCEPTS USED IN THE PAPER

Remark: A complete glossary of the concepts developed and used in our research can be found at: http://Seed.cs.colorado.edu/dynagloss.MakeGlossaryPage.fcgi

Cognitive Artifact: Cognitive artifacts are objects and environments that aid the human mind by complementing its abilities and by strengthening its mental powers. Domain-oriented design environments are part of a research agenda to identify and create unique possibilities for computational media as a cognitive artifact. Examples of cognitive artifacts are books, calculators, spelling correctors, and other computational tools.

Collaboratory: A Collaboratory is a new concept denoting the merging of "collaboration" and "laboratory."

Community of Practice: Community of practice is a group of practitioners who work as a community in a certain domain. One objective of domain-oriented design environments is to

support communities of practice through its domain-orientation which supports interaction at the level of the problem domain of the community of practice and not only on a computational level. Virtual communities of practice are supported with web-based domain-oriented design environments and with systems such as Behaviour Exchange and Dynasites.

Distributed Cognition: The knowledge which we have and need is not all in our minds, but to a large extent resides in the world (i.e., in artifacts of all kinds and in the minds of other people). A distributed cognition perspective raises many interesting issues: (1) how the knowledge in our heads and the knowledge in the world are related to each other; (2) how knowledge in the world can be learned on demand; and (3) whether we actively access the knowledge in the world or whether it is delivered to us.

Domain-Oriented Design Environments: Domain-oriented design environments are computational media that allow people to engage in more authentic tasks in their work practices by allowing them to deal with domains, and not fight with tools. Domain-oriented design environments make computers invisible and enable users to communicate with the problem domain rather than with computer tools. They extend construction kits by supporting not just the design of an artifact, but the design of a "good" artifact by increasing the back-talk of an artifact using critics. They support reflection-in-action as a design method. They are based on a multi-faceted architecture and are designed to use the seeding, evolutionary growth, reseeding process model.

Evolutionary Design of (Complex) Systems: Based on empirical findings that successful systems (software systems, buildings, cities) evolve, a paradigm shift is needed based on the following requirements: (a) software systems must evolve, they cannot be completely designed prior to use, (b) they must evolve at the hands of the users, and (c) they must be designed for evolution. Domain-oriented design environments, being based on the seeding, evolutionary growth, reseeding model, support evolutionary processes at the architecture level, the domain, and the artifact level.

Organisational Memory: Organisational memories provide shared information space for supporting a group of people (an organisation). The information space should be "living" in the sense that it is an evolving product of the work done by the members of the organisation as opposed to simply being a static storage of information.

Symmetry of Ignorance (or Asymmetry of Knowledge): Real world design problems transcend the knowledge of individuals and specific groups. All participants who have a stake in the design activity should be able to contribute their knowledge.

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